flint foundation carbon tool

The 2050 net zero carbon challenge requires new analytical tools to assess embodied carbon in engineering design. This flint foundation tool was developed by Dr Emma Hellawell through collaboration with Onyx Geo Consulting Ltd. The aim is to assess the upfront embodied carbon used in foundation options for a property/development and to evaluate potential carbon saving options. The tool currently compares two options, namely strip and piled foundations. At present the embodied carbon is evaluated for the following:

- Materials used within the foundation
- Transport of materials to site
- Excavation of soil and/or pile rig use.
- Waste disposal.

The tool also investigates potential carbon saving activities that a developer should consider, namely

- Potential reuse of excavated soil (on or offsite)
- The use of alternative concretes in the foundation.

Calculation

The general principles in calculating embodied carbon in this tool follow the calculations and appropriate parameters used in the Structural Carbon Tool from the Institution of Structural Engineering (IStruct E) [1,2]. The main differences between this tool and the IStruct E carbon tool relate to its direct application to strip and pile foundations and the inclusion of earthworks and material reuse options. Site activities are classified according to the general principles of life cycle assessment as detailed by RICS [3]. At this stage the tool addresses upfront carbon – i.e. in lifecycle stages A1-A5. The methods, many default values and life cycle categorisation follow established industry formats.

The embodied carbon is calculated as total carbon dioxide equivalent (tCO_2e) and includes carbon dioxide and other greenhouse gas emissions. For a process or product, this is typically calculated by multiplying the quantity of a material by a carbon factor for the process or production, i.e.

Embodied carbon (tCO_2e) = Material quantity (t) x carbon factor (tCO_2e/t)

For certain activities, e.g. landfilling of material, published carbon factors (e.g. GHG 2025 [4]) are used and in this case the value is multiplied by the mass of material landfilled.

There are however no published carbon factors for many site-based activities – e.g. excavating a strip trench, installing a pile mat. In this case carbon factors are estimated from the fuel use of the activity. For example, in excavating a strip trench the carbon factor is estimated based upon the typical diesel use for an excavator, the time taken to excavate in the particular soil type. In this case, site-based experience, data from quantity surveyors on excavation rate and guidance from industry has informed the values used in the tool.

The tool currently only includes the key work and hence embodied carbon involved directly in constructing a foundation. It does not include life cycle phases for use of the building use and end of life. Other current exclusions from the analysis are:

- Asset assessment
- Personnel transport to site
- Equipment transport to site
- Site activities external to foundations.

(These may be added later.)

Key assumptions/parameters used:

Concrete mix:

An appropriate concrete mix for foundations was selected based upon the guidance from Table 16 of RICS [3]. The carbon factor for this mix is detailed by IStruct E tool and can be calculated using the ICE V4 tool [5]. The baseline mix for the tool is C32/40 with 25% GGBS. The embodied carbon using alternative lower carbon options is calculated by the tool and those included and the carbon factors used are:

Table 1 – Material carbon factors

Material	Carbon Factor (tCO_2e/t)	Source
Concretes:		
25% GGBS replaced	0.113	IStruct E tool [1,2]
CEM II/A-L - 13% limestone - Portland-limestone cement	0.097	ICE V4 tool [5]
CEM II/B-V - 28% fly ash siliceous - Portland-fly ash cement	0.082	ICE V4 tool [5]
CEM III/A - 50.5% GGBS - Blast furnace cement	0.064	ICE V4 tool [5]
Steel		
Reinforcement bar	0.72	CARES [6]

The calculation is likely to show that inclusion of GGBS may lead to lower embodied carbon for the foundation works. However, due to the source of GGBS and its limited availability, using GGBS in concrete is unlikely to reduce global carbon emissions as the material would have been used elsewhere. Therefore, increasing its content in concrete is only recommended for technical reasons rather than carbon reduction requirements. It was included in this calculation as a demonstration of the potential of different concrete mixes in significantly reducing carbon emissions.

Steel

The carbon factor for steel depends upon the product, its production method and source material. The appropriate factor for reinforcement bars, based upon for UK sourced steel is used in the tool.

Transport

For consistency, transport of materials to site also follows the method and uses values outlined in the IStructE Carbon model.

Pile mat

The embodied carbon from using a pile mat includes the embodied carbon from the material source, its transport to site and the work in positioning the material for use. A general calculation for this is difficult as each site is different in handling this aspect, relating to the size of site, construction sequence and pile design. A calculation which included sourcing the material from construction waste and bringing it to site then positioning the pile mat for one property would significantly overestimate the embodied carbon. This calculation neglects issues such as reusing pile mat material between sites and the reposition of this material between properties onsite. At present the embodied carbon for the pile mat is calculated from the information detailed in table 2.

Table 2 – Pile mat parameters and assumptions

Parameter	Value	Source/ assumptions
Area	Footprint of property + extension 1m in each direction	Industrial advice
Depth	0.6m	Industrial advice
Width	2.0m beyond the outer wall of the property	Industrial advice
Source carbon factor	0.00061 tCO_2e/t – as this is assuming recycled construction source and extensive reuse.	Carbon factor for recycled construction aggregate is 0.0061tCO_2e/t from GHG Carbon Factors 2025 [4].
Transport to site	0.009tCO_2e/t	Transport for local sourced aggregate IStruct E Carbon Model [2].
Carbon factors for excavating from a spoil heap, moving, spreading and compacting material onsite	0.26808 tCO_2e/l Diesel emissions Diesel consumption of plant equipment Rate of work – (typically in m3/hr)	GHG Carbon factors 2025 [4]. Plant brochures and site data. Methvin's Production Rates Solution [8].
Moving material onsite using dumper truck	0.00009 tCO_2e/t	Assuming 12t dumper truck and movement of about 50m, based upon diesel emissions, quantity surveying data and GHG Carbon factors 2025 [4].

The pile mat calculation takes into consideration the number of properties on a site as this impacts the reuse of the pile mat and hence carbon emissions per property.
For the first property the calculation is:

Embodied Carbon Pile mat (Property #1) = Embodied carbon [Material source + transport to site + positioning material onsite.]

For the next property, the additional embodied carbon for the pile mat = embodied carbon [transport within site + positioning material onsite.]

The average embodied carbon for the pile mat for one property on a site of *n* properties is calculated as:

Pile mat embodied carbon (per property)	=	*[embodied Carbon Pile mat (Property #1) + embodied carbon (site transport and positioning material) * (n-1)] / n*

The embodied carbon is attributed to the appropriate life cycle assessment group (A1-A3, A4, A5). There is currently no embodied carbon attributed to waste from the pile mat as it is assumed the material is reused.

Waste

The format and parameters detailed in the IStruct E carbon model for determining embodied carbon due to waste from concrete and steel is followed. The same assumptions on waste factors are followed. The selected default parameters are shown in table 3.

Soil waste

The initial assessment assumes the worst case where all excavated soil is disposed of in a landfill. The assessment is then rerun for 2 options:

1. All material that can be reused is reused locally offsite. (This refers only to natural material as made ground **can not** be reused offsite (CL:AIRE [9].)
2. All excavated material is reused onsite. This includes made ground.

For offsite soil reuse, embodied carbon includes the following activities:

- Load material into trucks
- Transport material to new site (distance assumed to be 50km).
- Load, spread and compact material on new site.

The tool currently assumes the minimum movements of soil for reuse on or offsite. This is likely to be an underestimate as further loading and dumper truck movements may occur. This calculation is included to show that significant savings in embodied carbon can be achieved through soil reuse and NOT simply sending this resource to landfill.

This calculation requires information on the rate of carrying out activities, the fuel used for this and the embodied carbon for the fuel. The rate of carrying out an activity such as loading material varies depending on the equipment used (including bucket size) and soil geology. Quantity surveying data was used for the rates of these activities for the main soil types for the UK. The fuel use of plant was obtained from product specifications and confirmed through consultation with experienced site personnel.

Table 3 Carbon factors for waste and material reuse parameters

Parameter	Value	Source/ assumptions

Landfill disposal soil	0.01955 tCO_2e/t	GHG Carbon factors 2025 [4]
Landfill disposal C34 steel	0.001264 tCO_2e/t	GHG Carbon factors 2025 [4]
Landfill disposal C34 concrete	0.001263 tCO_2e/t	GHG Carbon factors 2025[4]
Transport to new site	0.009tCO_2e/t	Average transport for soil IStruct E Carbon Tool [2]
Carbon factors for excavating from a spoil heap, moving, spreading and compacting material onsite	0.00257 tCO_2e/l Diesel emissions Diesel consumption of plant equipment Rate of work – (typically in m3/hr)	GHG Carbon factors 2025 [4] Plant brochures and site data. Methvin's Production Rates Solution [8]

For reuse of material onsite, the calculation includes the carbon used in loading, moving, spreading and compacting the material.

Uncertainty

There are many sources of uncertainty within any embodied carbon calculation and hence the user should be aware that this is not an exact science, but an estimate of the embodied carbon in a proposed foundation. There are uncertainties inherent within the carbon factors, material quantities and estimations that are part of any site work. The embodied carbon results should therefore not be quoted as exact values (of tCO_2e) but instead used to compare the embodied carbon in design and foundation options.

References/ Sources of data

The following references and databases were used within the tool:

1. The Institution of Structural Engineers and Elliott Wood Partnership Ltd 2025 *The Structural Carbon Tool – version 3*. Available at: https://www.istructe.org/resources/guidance/the-structural-carbon-tool/ [Accessed: January 2025].
2. The Institution of Structural Engineers and Elliott Wood Partnership Ltd 2025. *How to calculated embodied carbon*, 3rd Edition, Gibbons, O.P, Orr, J.J and Arnold,W., Available at https://www.istructe.org/resources/guidance/how-to-calculate-embodied-carbon/ [Accessed January 2025].
3. RICS. *Whole life carbon assessment (WLCA) for the built environment (2nd edition)*. Available at:https://www.rics.org/profession-standards/rics-standards-and-guidance/sector-standards/construction-standards/whole-life-carbon-assessment [Accessed: January 2025].
4. *HM Government, Department for Energy, Security and Net Zero (2025) UK Government GHG Conversion Factors for company reporting. Methodology Paper for Conversion factors. See https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2025*, *https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting*

5. Circular Ecology. *The Inventory of Carbon and Energy (The ICE Database)*. Available at: https://circularecology.com/embodied-carbon-footprint-database.html [Accessed: January 2025].
6. CARES. *Understanding UK average embodied carbon emissions for steel reinforcing bar. Ladin Camci, Dave Knight, August 2024* Available at: https://www.carescertification.com/content/HtmlContent/d7cc4369-ff70-4b95-8c62-24b076626737/1f3382f3-e62f-4e13-94d7-cb9bbfa431ab/240812%20CARES%20Understanding%20UK%20average%20embodied%20carbon%20emissions%20for%20steel%20reinforcing%20bar_FINAL.pdf [Accessed: August 2025].
7. BECD. *Welcome to the Built Environment Carbon Database version 1.0.0*. Available at: https://carbon.becd.co.uk/ [accessed February 2025].
8. Methvin's Production Rates Solution, Available at https://methvin.co/production-rates/estimating-production-rates/foundations [Accessed January 2025].
9. CL:AIRE 2011, DoWCoP – The Definition of Waste: Development Industry Code of Practice, Version 2, available at https://claire.co.uk/projects-and-initiatives/dow-cop/28-framework-and-guidance/111-dow-cop-main-document